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Sensory and analytical comparison of orange-fleshed honeydew to cantaloupe and green-fleshed honeydew for fresh-cut chunks

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Abstract

Maintaining the sensory, microbial and postharvest quality of fresh-cut fruit after processing and throughout distribution and marketing is a major challenge facing the fresh-cut fruit industry. Fresh-cut chunks of orange-fleshed honeydew ('Honey Gold', 'Orange Dew', 'Temptation' and three breeding lines) and green-fleshed honeydew ('Honey Brew') and an orange-fleshed cantaloupe ('Cruiser') harvested at commercial and full-slip maturities were compared after storage for 0–11 days in air at 5 °C. Fresh-cut cantaloupe had higher respiration and ethylene production rates, aromatic volatile concentrations, and β-carotene/chroma and orange hue (except 'Orange Dew') than those of honeydew whereas honeydew chunks generally had higher soluble solids content (SSC), Kramer firmness and lower microbial counts than cantaloupe chunks. All genotypes had similar ascorbic acid levels. During storage, analytical quality characteristics of fresh-cut chunks from all genotypes were well maintained even though microbial populations increased especially on cantaloupe chunks. Consumers liked the flavor, texture, sweetness and overall eating quality of the orange-fleshed honeydew genotypes as well as or better than those of cantaloupe and green-fleshed honeydew. 'Orange Dew' scored highest in appearance and had the highest β-carotene concentration, chroma and orange hue among orange-fleshed honeydew genotypes whereas 'Temptation' generally scored highest for flavor intensity and acceptability and overall eating quality; and it had the highest aromatic volatile concentrations among the orange-fleshed honeydews. Many individual volatiles were identical in cantaloupe and honeydews; however, honeydew genotypes, particularly 'Temptation', were distinctive from cantaloupe and green-fleshed honeydew in having relatively high levels of various nonenyl and nonadienyl acetates having honeydew-like or uncharacterized aromas. Fresh-cut chunks from full-slip melons generally had higher analytical and sensory quality characteristics but higher microbial counts and lower shelf stability compared to those from commercially mature fruit. The results indicate that orange-fleshed honeydews are a promising new melon type for fresh-cut processing.

Keywords: *Cucumis melo*; Quality; Respiration and ethylene production rates; Volatiles

1. Introduction

In the past decade, fresh-cut produce has been a rapidly growing segment of the produce industry and now accounts for over 10% of all produce sales in the United States. While fresh-cut vegetables have a significant market share, the fresh-cut fruit category is also contributing to the rapid growth of the fresh-cut industry as processors and fruit marketers are placing increased emphasis on the development of the fresh-cut fruit market. The fresh-cut fruit category is expected to exceed US$1 billion by 2008 (Clement, 2004).

Orange-fleshed cantaloupe (*C. melo* L., Reticulatus Group) and green-fleshed honeydew (*C. melo* L., Inodorus Group) (hereafter referred to as cantaloupe and green honeydew, respectively) melon chunks are common components of fresh-cut fruit products and are available year-round throughout the United States. However, netted melons, such as cantaloupe, have a rough uneven rind that is more difficult to sanitize than the relatively smooth surfaces of honeydews

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(Suslow and Cantwell, 2001; Ukuku et al., 2004), and thus cantaloupe in particular has been associated with numerous outbreaks of foodborne illness in recent years (Center for Disease Control, 1991, 2002; Dewaal et al., 2000). While high temperature treatments of cantaloupes are promising, but not completely effective, precutting sanitation procedures (Suslow and Cantwell, 2001; Ukuku et al., 2004), they can also adversely affect melon taste (Teitel et al., 1989) and have yet to be adapted for large-scale commercial use.

Smooth skinned orange-fleshed honeydews (hereafter referred to as orange honeydew) have become increasingly available in the United States and offer a potentially more microbially safe alternative to fresh-cut cantaloupe as well as offering more variety that consumers desire in fresh-cut fruit products. Since cantaloupes and honeydews are packaged in 40 and 30-lb boxes, respectively, fruit processors are also interested in orange honeydews from a workman's compensation perspective. While honeydews in general have a lower respiratory rate and longer storage life than cantaloupes (Kader, 1992), the keeping quality of various orange honeydew genotypes as a fresh-cut product has not been evaluated or compared to that of cantaloupe or green honeydew.

'Orange Dew' is one of the most extensively grown and commercially available orange honeydews. Other orange honeydew genotypes grown in the United States are 'Temptation', 'Honey Gold' and a number of breeding lines that are being tested by various seed companies. The genetic origin of these orange honeydews can be quite complex and not well defined or it may be proprietary. However, one way to introduce orange hue, i.e., β-carotene production, into green honeydews is to include a backcross with cantaloupe or another orange netted melon at an early stage in the breeding program (Kevin Crosby, personal communication). As such, orange honeydew genotypes may be more genetically diverse and more subject to variations in fruit quality characteristics and storage life than green honeydews.

Besides genetics and breeding programs, melon quality is also affected by cultural practices, weather conditions and maturity at harvest (Beaulieu et al., 2004; Robertson and Decker-Walters, 1999). In the United States, the commercial practice for harvesting cantaloupe is to wait until the melons are 3/4 slip or full slip, i.e., when the abscission zone between the fruit and the stem (peduncle) is 3/4 to fully formed. Cantaloupe harvested at full slip has a shorter shelf-life; and firmness and flavor losses may occur before completion of the marketing process (Hoover, 1955). Honeydews are later maturing than cantaloupe, allowing more time for photosynthates to enter the fruit and thereby increase SSC and fruit sweetness. Minimal commercial maturity is mature, unripe fruit containing an SSC of 10% (stage 1, Kasmire and Cantwell, 1992). Ripening (stage 2) and ripe (stage 3, abscission zone forming) honeydews are also commercially harvested in the United States. Ripe honeydews are considered ideal for eating but have a shorter shelf-life than less mature fruit.

We compared fresh-cut chunks of cantaloupe and honeydews at different maturities for fruit quality characteristics and microbial quality during storage in air at 5 °C for up to 11 days. The overall objective of this study was to determine the feasibility of using orange honeydews for fresh-cut processing.

2. Materials and methods

2.1. Plant material

In 2003 and 2004, cantaloupe (*C. melo* L., Reticulatus Group, 'Cruiser'), green ('Honey Brew') and orange ('Temptation', breeding lines 4470, 4471, and 4524) honeydews (*C. melo* L. Inodorus Group) were grown in commercial melon fields at Rio Grande City, TX. The 2004 planting included two additional orange honeydews, 'Orange Dew' and 'Honey Gold'. In 2003, cantaloupe were harvested at 3/4 slip (usual commercial maturity) and honeydew at or near minimal commercial maturity (stage 1 = mature unripe) when SSC of all genotypes including cantaloupe was similar. In 2004, two harvests were made. In the first harvest, cantaloupe were picked at 3/4 slip and the honeydews at stage 2 (mature ripening) hereafter referred to as commercial maturity. For the second harvest, all genotypes were harvested at or near full slip (mature ripe, honeydew at stage 3) hereafter referred to as full slip. Any fruit that had water-soaked flesh or otherwise appeared overripe were discarded.

After each harvest, fruit were packaged in plastic coolers and shipped overnight to Beltsville, MD, then stored an additional day at 10 °C before fresh-cut processing. Two days after harvest, 12–20 fruit from each genotype were surface sanitized by dipping for 5 min in a 200 μL L^{-1} NaClOH solution adjusted to pH 6.0 using 1 M HCl, blotted with a paper towel and processed at 10 °C using equipment cleaned with 70% (v/v) ethanol. For each genotype, the melons were separated into three or four groups of four fruit (three replicates in 2004 and four replicates in 2003) and each fruit was uniformly peeled on a Muro CP-44 Melon Peeler (Tokyo, Japan). The blossom- and stem-ends were discarded, each fruit was sliced once longitudinally with a sharp knife, seeds and placental tissue were removed and ∼2.5 cm latitudinal slices were prepared using a 0.2 mm-thick stainless steel strap (Ace Co., Boise, ID, USA) held taut in a hacksaw. Preliminary experiments indicated that strap slicing produced a fresh-cut product essentially identical to that from commercial melon-cutting equipment. The strap slicer was also used to prepare 2–3 cm wide chunks in trapezoidal shaped wedges from the melon slices. After chunks from each four-fruit replicate were randomized, samples were removed for respiration and ethylene production rate measurements, microbial analysis and ascorbic acid and β-carotene determinations (see below). Replicate samples for sensory analyses in 2003 were placed in lidded 5.2-L plastic containers, stored for 2 days at 5 °C and vented daily to maintain aerobic conditions. The remaining

chunks were placed in 1-L lidded plastic containers (number of containers varied depending on replicate size), each container was sealed with parafilm and the container vented using a 0.2 μm filter. Preliminary experiments indicated that the O_2 and CO_2 concentrations within the containers remained at or near ambient air levels. Samples were stored 0–11 days at 5 °C.

2.2. Analyses of CO_2 and ethylene

Respiration and ethylene production rates of melon chunks (150 g) from each replicate of each genotype were monitored every 6 h during a 10- or 11-day period at 5 °C after fresh-cut processing (Saftner et al., 1999). Humidified 0.2 μm-filtered air was passed through sealed glass jars containing the melon chunks. Carbon dioxide and ethylene contents of the outlet streams were monitored using a CO_2 analyzer (Model CD-3A; Ametek, Pittsburgh, PA, USA) and a gas chromatograph (GC, Model 5890a Series II; Agilent Technologies, Rockville, MD, USA) equipped with a flame ionization detector (FID).

2.3. Analytical quality measurements

Flesh color, texture, SSC, ascorbic acid, β-carotene and aromatic volatile concentrations were measured on melon chunks of all genotypes at the time of cutting and following 2, 5, 7, or 8 days and 10 or 11 days storage in air at 5 °C. Flesh color (CIE L^*, a^*, b^*) was measured on a latitudinal cut using a Minolta chroma meter (Model CR-300, Tokyo, Japan) calibrated using a white tile. One L^*, a^*, and b^* reading was taken from each of five melon chunks of each replicate sample. Results were expressed as lightness (L^*), chroma ($C^* = [(a^*)^2 + (b^*)^2]^{0.5}$), and hue angle ($h_{ab} = \tan^{-1}\ [(b^*)(a^*)^{-1}]$). In the second harvest season, chunks of 'Temptation' and 'Honey Gold' had distinct orange hue by the placental region transitioning to a green hue near the rind of many chunks, and color readings were selectively taken from the orange hued regions of bi-colored chunks.

Kramer firmness was measured with a shear-compression cell (Model CS-1) attached to a Texture Test System (Model TMS = 90; Food Technology Corporation, Rockville, MD, USA) using a stroke speed of 1 cm s^{-1}. Chunks in 100 g subsamples from each replicate were placed in the cell randomly. Results are presented as the mean maximum force (F_{max}) from three replicate samples. Juice expressed from each sample during texture measurement was analyzed for SSC using a digital temperature-compensated refractometer (Model PR-101; Atago Co., Tokyo, Japan). Expressed juice from texture measurements was also used for volatile measurements.

For volatile analyses, 1 mL of expressed juice from each texture measurement was transferred to a 4-mL vial containing 0.3 mL of 3 M $CaCl_2$, the vial capped with a Teflon-lined septum and the sample stored for up to a month at −20 °C before being analyzed. Analysis of aromatic volatile concentration using a solid-phase microextraction (SPME; Suppelco Co., Bellefonte, PA, USA) technique for volatile collection over a 16 min sorption period and GC-FID (Model 6890; Agilent Technologies, Rockville, MD, USA) for volatile separation and quantification was performed as previously described (Saftner, 1999). Constructing calibration curves for each volatile analyte in each melon juice sample is not feasible and thus total volatile and individual volatile concentrations are reported in detector response units of picoamperes (pA) rather than absolute amounts (Saftner et al., 2002). For volatile identification, a GC–mass spectrometer (MS) procedure was used as previously described (Saftner et al., 2002). Identification of volatile components was confirmed by comparison of collected mass spectra with those of standards and spectra in the National Institute for Standards and Technology (NIST) mass spectral library, Search Version D.04.00 (Agilent Technologies, Rockville, MD, USA).

For ascorbic acid analyses, two chunks from each replicate were frozen in liquid N_2 and stored for up to 40 days at −80 °C before analyses. Ascorbic acid was extracted from the chunks by polytron homogenizing 5 g of frozen tissue with 10 g of extraction solution (20 mM KH_2PO_4, 1 mM ethylenediaminetetraacetic acid (EDTA), 0.1 mM diethyldithiocarbamic acid (EDC) and 5 mM 1,4-dithiothreitol (DTT) at pH 3.0) for 30 s at setting 5 and the crude extract was filtered through a 0.45 μm nylon filter. Ascorbic acid was separated by HPLC (Model 600 with autoinjector, Model 717+, Waters Chromatography, Milford, MA, USA) using a 4.6 mm × 250 mm reverse phase C_{18} column (5 μm particle size; Separations Methods Technologies, Newark, DE, USA). Ascorbic acid was eluted isocratically with 20 mM KH_2PO_4 solution at a flow rate of 16.7 μL s^{-1}, and was detected with an in-line UV detector (Model LC95, Perkin-Elmer, Norwalk, CT, USA) set at 245 nm. Known concentrations of ascorbic acid in extraction solution were identically handled and quantification was done using a peak height calibration procedure. Preliminary experiments indicated that ascorbic acid solutions were stable throughout tissue extraction and HPLC analysis.

For β-carotene analyses, three fresh-cut chunks from each replicate in 2004 were frozen in liquid N_2, freeze dried and the dried tissue pulverized. The β-carotene in the powdered samples was extracted, separated by HPLC and quantified essentially according to the procedure of Sadler et al. (1990). Results are reported as mg kg^{-1}.

2.4. Microbial quality measurements

For each replicate melon sample, two fresh-cut chunks (∼35 g) were placed in a stomacher bag with 100 mL of phosphate-buffered saline (PBS at 100 mM, pH 7.0) and then blended in a Stomacher blender (Stomacher 80; Stewart Medical, London, England) for 1 min at normal speed. The resultant slurry was filtered through glass wool, serially diluted with PBS if necessary to ensure countable concentrations and was then plated in duplicate onto tryptic soy

agar (TSA; Difco Laboratories, Detroit, MI, USA) supplemented with 100 mg L^{-1} cycloheximide and onto potato dextrose agar (PDA; Difco Laboratories, Detroit, MI, USA) supplemented with 50 mg L^{-1} chloramphenicol using a spiral plater (Autospiral DW; Don Whitley Scientific Limited, West Yorkshire, England). After 42 h of incubation at 37 °C (TSA-cycloheximide) or 30 °C (PDA-chloramphenicol), the plates were read with a Protos plate reader (Synoptics Ltd., Cambridge, England). Aerobic bacterial counts from TSA-cycloheximide plates and fungal (yeast and mold) counts from PDA-chloramphenicol plates are reported as log CFU kg^{-1}.

2.5. Sensory analyses

We had access to a large group of consumers of very mixed ages and backgrounds at a public field day at the USDA Agricultural Research Center (Beltsville, MD, USA) on 7 June 2003. About 500 panelists of both genders and of ages from 8 to 78 evaluated chunks of three genotypes; cantaloupe ('Cruiser'), green honeydew ('Honey Brew') and one of four orange honeydew genotypes ('Temptation' and breeding lines 4470, 4471, or 4524). Children <12-years-old were accepted only if they understood the task, could discriminate and could express their opinions; the children were closely supervised. Evaluations were done under ambient conditions at ~35 °C in a translucent white tent. Panelists were not isolated but were encouraged not to share opinions or otherwise bias other panelists.

Melon chunks of the various genotypes were processed as described above and stored for 2 days at 5 °C under aerobic conditions. Containers were embedded in crushed ice during the serving period of about 90 min per replicate. Paper plates (23 cm) were partitioned into three sections, each labeled with a three-digit code, and chunks of cantaloupe, green honeydew, and one of the orange honeydew genotypes were placed beside their respective code number. Different code numbers were used for each of four replicates of 120 consumers. Panelists were given verbal instructions and a paper ballot with the three-digit codes and 15-cm unstructured hedonic scales labeled *really bad* to *super good* at the ends, later digitized to 0–100, respectively. Panelists were told to cleanse their palates with a bite of low-salt saltine cracker and a sip of room-temperature water before each sample. Acceptability of texture, flavor and overall eating quality were evaluated. Panelists were asked to indicate gender and age in decades and encouraged to give comments.

In 2004 we conducted in-house consumer panels; and two additional orange honeydews, 'Orange Dew' and 'Honey Gold', were added to better represent commercially available orange honeydews. Beltsville Agricultural Research Center staff who like melons and had no knowledge of the research project evaluated fresh-cut chunks of all of the genotypes at two fruit maturity levels (commercial maturity and full slip) harvested over a three-week period. Volunteers were solicited by email from about 1200 employees. Fresh-cut melon chunks were prepared as described above and stored for 5 days at 5 °C under aerobic conditions, followed by 2 h at 23 °C to enhance perception of aroma and taste characteristics. Sensory terminology and scale anchors were selected by the authors during a preliminary discussion panel with experienced sensory panelists. Each named cultivar was evaluated by 120 consumers at commercial and full-slip maturities, with about 30% duplication of panelists over maturity levels. The number of melons available for the three breeding lines restricted the number of evaluations to 60 consumers per line. Order of the genotypes was randomized among sessions to minimize flavor carry-over effects, using the same order for 10 panelists within a panel session. Samples were presented one at a time in individual booths under moderate incandescent lighting. Panelists were required to cleanse their palates with a bite of low-salt saltine cracker, a sip of room-temperature water and a small lag time before each sample. The panelists rated texture (mushy to firm), sweetness (none to very sweet) and melon flavor (none to very strong) and acceptability of appearance, texture, flavor and overall eating quality (bad to good) on unstructured 15-cm line scales, converted to scores of 0–100. Comments were solicited on the ballots. On-screen ballots were prepared and data were collected using Compusense *Five* (Version 4.2; Compusense Inc., Guelph, Ontario, Canada). For all sensory evaluations in 2003 and 2004, instrumental tests were performed on corresponding replicate samples of melon chunks of all genotypes.

2.6. Statistical analyses

Data were analyzed using SigmaStat (Version 3.0; SPSS Inc., Chicago, IL, USA) and SAS PROC MIXED (SAS, 1999). For instrumental measurements sources of variation were genotypes (6 in 2003 and 8 in 2004) and storage duration (5). For sensory evaluation of melon chunks in 2003, sources of variation were genotypes (6) and replicates (4). For sensory evaluations in 2004, sources of variation were genotypes (8) and maturities (2) considered fixed and the panel sessions (6 or 12) and panelists (60 or 120) considered random. Treatment differences were tested by Sidak-adjusted means comparison ($\alpha \leq 0.05$). All differences mentioned were significant at $\alpha \leq 0.05$ unless stated otherwise.

3. Results and discussion

3.1. Respiration and ethylene production rates

In 2003, the respiration rate of fresh-cut chunks of cantaloupe and honeydew were similar (Fig. 1a). In 2004, fresh-cut chunks of cantaloupe and 'Orange Dew' had higher respiration rates than those of the other honeydews, whether processed from commercial (Fig. 1b) or full-slip (Fig. 1c) melons. Intact cantaloupes generally have higher respiration and ethylene production rates, are faster maturing and have less shelf stability than honeydews (Kader, 1992; Robertson

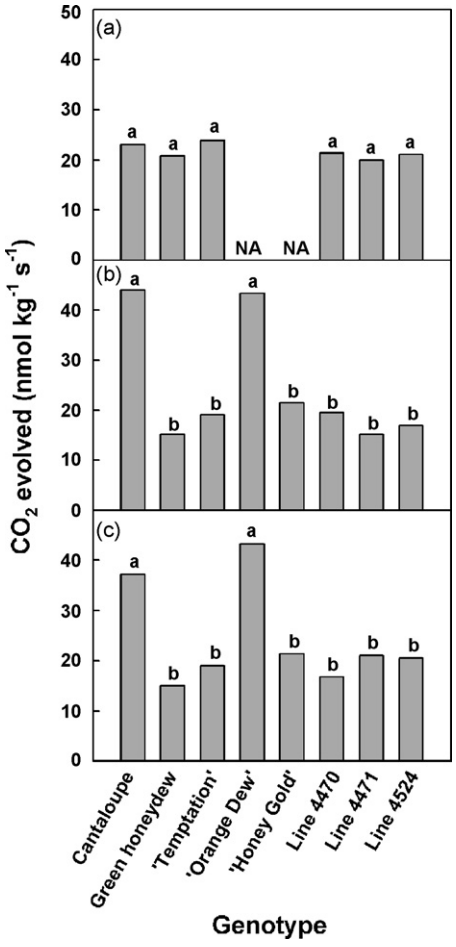

Fig. 1. Respiration rate, as CO_2 evolved, of fresh-cut chunks from various genotypes of melon harvested at commercial maturity in 2003 (panel a), and 2004 (panel b) and at full-slip maturity in 2004 (panel c). Within panels, bars labeled with the same letter are not significantly different using Sidak-adjusted means comparison ($\alpha \leq 0.05$).

and Decker-Walters, 1999). Specifically, the respiration rate of cantaloupe chunks in the second year was almost double what it had been in the first year, suggesting that the cantaloupe processed in 2004 were in a more stressed condition than those processed in 2003. Except for 'Orange Dew' and 'Honey Gold', which were evaluated only in 2004, fresh-cut chunks of the green and orange honeydew genotypes had similar respiration rates within a growing season or across growing seasons. Honeydews are known to be more tolerant of adverse growing conditions than cantaloupe and the weather during the second growing season was much cooler (mean maximum and mean minimum temperature >5 °C lower), wetter (2.7 cm vs. 13.9 cm rainfall) and overall less favorable for melon growing than that in 2003. Since 'Orange Dew' had a respiration rate similar to that of cantaloupe suggests that 'Orange Dew' may have been hybridized to a cantaloupe or another orange netted melon at some point during its breeding program for orange flesh. In support of this hypothesis, several of the 'Orange Dew' fruit used in this study had a slight amount of netting on their rinds.

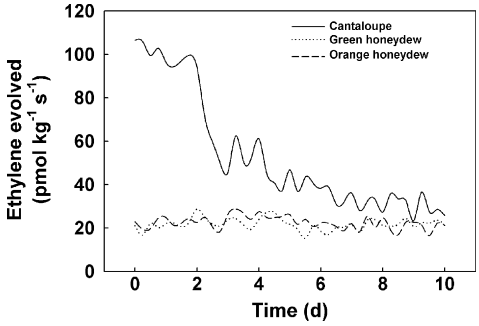

Fig. 2. Ethylene production rate of fresh-cut chunks processed from cantaloupe and orange and green honeydews harvested at commercial maturity in 2003 and stored for 10 days in air at 5 °C. Each plot is the mean of four replicate samples.

The ethylene production rate of fresh-cut cantaloupe also was higher than that of the honeydews during most of the 10-d storage period in 2003 (Fig. 2) and 2004 (data not shown). The relatively high respiration and/or ethylene production rates in cantaloupe and 'Orange Dew' chunks may be indicative of fast ripening—fast senescing genotypes and/or ones highly prone to wound respiration and ethylene production.

3.2. Analytical quality analyses

The cut-surface chroma (C^*) and hue angle (h_{ab}) of orange honeydew chunks was generally intermediate between those of green honeydew and cantaloupe, the exception being 'Orange Dew', which had the same degree of color saturation and orange hue as cantaloupe (Fig. 3). The orange hue in orange melons is primarily due to high concentrations of β-carotene (Lester and Eischen, 1996; Robertson and Decker-Walters, 1999). The β-carotene concentration of cantaloupe, 'Orange Dew' and the three orange honeydew breeding lines was the same (range 14–17 mg kg^{-1}). The β-carotene concentration of 'Temptation' and 'Honey Gold' (8 mg kg^{-1}) was intermediate between those of cantaloupe (16 mg kg^{-1}) and green honeydew (1 mg kg^{-1}), and was probably due to incomplete orange coloration of their flesh in 2004 when the melons were grown under less-than-favorable weather conditions. All cantaloupe and honeydew genotypes had the same lightness ($L^* = 62$–67) (data not shown). Overall, the results show that 'Orange Dew' chunks had the same cut surface color and β-carotene concentration as cantaloupe chunks whereas the other orange honeydews had surface colors intermediate between cantaloupe and green honeydew.

A catabolite of β-carotene is Vitamin A, which is >80 times more abundant in orange netted melons such as cantaloupe than in green honeydews (Robertson and Decker-Walters, 1999). While we did not measure the Vitamin A content of orange honeydews, the greater β-carotene concentration in orange versus green honeydews would imply that the Vitamin A concentration would also be higher in orange than in green honeydews. The ascorbic acid concentration of all of the melon genotypes evaluated was the same

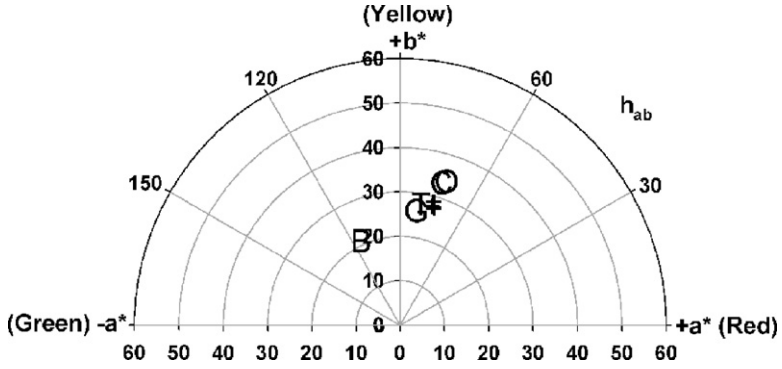

Fig. 3. Partial a^* and b^* chromaticity diagram showing the chroma and hue angle of the cut surface of melon chunks processed from cantaloupe (C), 'Honey Gold' (G), 'Orange Dew' (O), 'Temptation' (T), three orange honeydew breeding lines (+) and green honeydew (B). Each symbol is the mean of three replicate samples measured at 0, 2, 5, 7, and 10 days storage ($N = 15$).

and ranged between 140 and 198 mg kg^{-1} (data not shown). With respect to these phytonutrients, the nutritive value of orange honeydews is as good as or better than that of green honeydews.

Full-slip honeydews generally have higher SSC and a sweeter taste than cantaloupes and other orange netted melons (Robertson and Decker-Walters, 1999). Unfortunately, full-slip melons have a short shelf-life; and over-ripening and flavor loss may occur before completion of the marketing process (Hoover, 1955; Pratt et al., 1977). Melons harvested prior to full slip are generally not as high in SSC and aromatic volatile concentrations but have longer storage potential (Beaulieu et al., 2004; Robertson and Decker-Walters, 1999). Depending on the stage of maturity at harvest, orange and green honeydew genotypes had as much or more SSC than cantaloupe (Table 1). In 2003, fresh-cut chunks of honeydew genotypes had the same SSC as those of cantaloupe. However, for the 2004 commercial maturity melons, the honeydew cultivars, but not the orange honeydew breeding lines, had higher SSC than cantaloupe. At full-slip maturity, all honeydew genotypes except breeding line 4524 had a higher SSC than cantaloupe. In 2004, the SSC of all honeydew genotypes increased between 0.3 and 3.0% between the first and second harvests, whereas the SSC of cantaloupe was not improved by allowing the fruit to fully ripen on the vine. The 2004 SSC results are consistent with the general observation among melon growers that honeydew genotypes grow better and develop better quality fruit than cantaloupe under adverse growing conditions. The difference in SSC between honeydews harvested in 2003 and corresponding fruit harvested in 2004 was variable and again was probably due, at least in part, to the less favorable melon growing conditions in 2004 compared to 2003. During storage, no consistent pattern of change in SSC among any of the genotypes was observed (data not shown).

Table 1
Soluble solids content (SSC) for fresh-cut melon chunks from cantaloupe and honeydew genotypes

Genotype	SSC in year 2003 (%) commercial maturity	SSC in year 2004 (%)	
		Commercial maturity	Full slip
Cantaloupe	9.5a	8.0c	7.9c
Green honeydew	9.5a	9.2bc	12.2a
Temptation	9.9a	10.6ab	11.0a
Orange Dew	–	11.9a	12.2a
Honey Gold	–	11.0a	12.0a
Line 4470	9.4a	8.6c	9.5b
Line 4471	10.2a	8.0c	9.5b
Line 4524	10.0a	8.5c	9.0bc

In year 2003, fruit of all genotypes were harvested at a commercial maturity when SSC was at or near 10% (Kasmire and Cantwell, 1992). In year 2004, fruit were harvested at commercial and full-slip maturities. Means within the same column followed by the same letter are not significantly different by Sidak-adjusted means comparison ($\alpha \leq 0.05$).

All of the aromatic volatiles identified in this study (Table 2) have been previously reported in melons (Beaulieu et al., 2004; Buttery et al., 1982). There are distinct qualitative and quantitative differences in aromatic volatiles among melon genotypes (Wyllie et al., 1989) with concentrations of many volatiles, particularly the more abundant esters, being generally higher in cantaloupe than in honeydews (Wyllie and Leach, 1992; Yabumoto et al., 1978). Juice extracts from fresh-cut 'Temptation' generally had aromatic volatile concentrations intermediate between those of cantaloupe and green honeydew (Table 2). However, 'Temptation' (Table 2) and the other orange honeydew genotypes (data not shown) were distinctive from cantaloupe and the green honeydew in having relatively high concentrations of nonenyl and nonadienyl acetates having honeydew-like or uncharacterized aromas. Due to the low odor thresholds of unsaturated C_9 alcohols and their acetates, they are considered to be major contributors to honeydew melon aroma (Buttery et al., 1982). Sulfur-containing compounds, which also have low odor thresholds and are believed to play an important role in the overall aroma profile of melon fruit, especially cantaloupe (Wyllie and Leach, 1992), were not detected in this study despite specific efforts to do so. Except for the C_9 acetates and alcohols, most of the volatiles identified in Table 2 are fairly common in fruits and are not specifically characteristic of melon. The acetate ester concentrations and

Table 2
Recorder response of aromatic volatiles recovered by SPME from tissue extracts of fresh-cut melon chunks stored for 2 days in air at 5 °C after processing from 2003-grown cantaloupe, 'Temptation' and green honeydew fruit

Chemical name	RI	Detector response (pA)			Aroma
		Cantaloupe	'Temptation'	Green honeydew	
Ethyl acetate	605	99.0b	169.5a	36.8c	Pineapple, ethereal
Methyl butyrate	717	16.4a	17.2a	ND	Fruity
Ethyl isobutyrate	751	13.6b	21.5a	ND	Fruity, floral
Isobutyl acetate	768	88.7a	82.6a	0.4b	Sweet, fruity
Methyl 2-methylbutyrate	772	0.4	ND	ND	Fruity, sweet
Ethyl butyrate	803	159.6a	21.5b	8.9c	Fruity, sweet
Butyl acetate	812	69.7a	48.3b	0.5c	Fruity
Ethyl 2-methylbutyrate	846	159.8a	126.2a	8.4b	Green, fruity
Isoamyl acetate and 2-methylbutyl acetate	876	296.8a	269.9a	13.0b	Fruity, sweet, Fruity, banana
Ethyl valerate	900	25.0a	32.4a	3.3b	Fruity, apple
Amyl acetate	912	1.2c	12.5a	4.4b	Banana, ethereal
Methyl hexanoate	922	12.3a	6.1b	0.4c	Pineapple, ethereal
Isobutyl butyrate	953	0.9a	1.4a	ND	Fruity, ethereal
Benzaldehyde	962	1.2a	1.5a	ND	Aromatic, sweet
Ethyl hexanoate	999	297.4a	245.0b	3.4c	Fruity, apple
(*Z*)-3-Hexenyl acetate	1004	145.2a	82.0b	3.0c	Green, fruity
Hexyl acetate	1011	252.6a	136.9b	5.9c	Apple, cherry
Isobutyl isobutyrate	1040	2.9a	1.2b	ND	Ethereal, fruity
1-Octanol	1070	1.2	<0.3	ND	Fatty
Ethyl (*E*)-4-heptenoate	1090	1.5	ND	ND	Unknown
Ethyl heptanoate	1099	<0.3	ND	ND	Wine-like, fruity
Nonanal	1104	26.8a	11.6b	9.1b	Fatty, melon
Heptyl acetate	1111	15.5a	4.1b	0.4c	Woody, oily
(*Z*)-3-Nonen-1-ol	1155	ND	2.7	<0.3	Melon
(*E*)-2-Nonenal	1162	2.7b	6.9a	5.5a	Melon
Benzyl acetate	1164	57.6a	60.5a	5.4b	Sweet, fruity
(*Z*)-6-Nonen-1-ol	1171	<0.3	1.4	<0.3	Melon
Ethyl benzoate	1172	4.4	<0.3	ND	Floral, fruity
Ethyl octanoate	1194	9.7a	8.4a	1.8b	Fruity, floral
Octyl acetate	1213	15.4a	11.1a	4.0b	Fruity, floral
Phenylethyl acetate	1255	3.6b	7.3a	3.8b	Unknown
Nonyl acetate	1256	1.8b	15.0a	1.9b	Fruity
(*Z*)-3-Nonenyl acetate	1261	2.4b	53.6a	1.2b	Unknown
(*Z*)-6-Nonenyl acetate	1263	2.5b	42.6a	2.9b	Honeydew
(*Z,Z*)-3,6-Nonadienyl acetate	1265	2.6c	25.4a	14.7b	Unknown
Ethyl decanoate	1392	8.2a	3.2b	0.9c	Oily, fruity
Geranyl acetone	1448	3.1b	12.5a	ND	Fresh, rosy
α-Farnesene	1496	<0.3	ND	ND	Unknown

RI: retention index based on retention times of identified compounds, calculated from linear equation between each pair of straight chain hydrocarbons (C_5–C_{15}). Aroma is the organoleptic property of individual purified compounds (Aldrich, 2003; Bedoukian Research, 1999; Buttery et al., 1982). Means within the same rows followed by the same letter are not significantly different by Sidak-adjusted means comparison ($\alpha \leq 0.05$). ND: not detected. GC peaks for isoamyl acetate and 2-methylbutyl acetate co-eluted. (*Z,Z*)-3,6-nonadienyl acetate identification is tentative: mass spectral data was identical to those of acetylated (*Z,Z*)-3,6-nonadienol.

the total volatile concentration were higher in 'Temptation' than in the other orange honeydews, but all orange honeydew genotypes had higher acetate ester and total volatile concentrations than the green honeydew (data not shown). These results suggest that cantaloupe had the strongest aroma, followed by 'Temptation', other orange honeydew genotypes and green honeydew.

During storage of fresh-cut chunks processed from commercially mature melons, the total volatile concentration generally increased during the first 2 days of storage, and then remained relatively stable or decreased gradually during the remainder of storage (Fig. 4). Individual volatile concentrations generally followed the same pattern (data not shown). During storage, the total aromatic volatile concentration of fresh-cut chunks of orange honeydews was 1.2–7.5 times higher than that of green honeydew chunks, with 'Temptation' being the highest. Total volatile concentration in cantaloupe chunks was >1.6-fold higher than that of 'Temptation' and >6 times higher than that of the green honeydew. The aromatic volatile concentrations were generally, but not always significantly, higher in fresh-cut chunks processed from full-slip fruit than those from less mature fruit (data not shown). Beaulieu et al. (2004) has shown that aromatic volatile concentrations generally increase during melon maturation and ripening. From these data, it is reasonable to expect that melon aroma

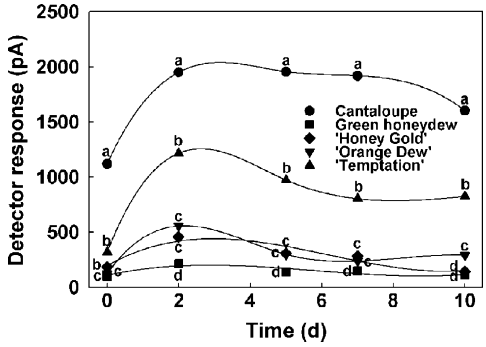

Fig. 4. Total aromatic volatile concentration, reported in FID area response units of picoamperes (pA), in the headspace above juice extracts of fresh-cut chunks processed from cantaloupe, 'Honey Gold', 'Orange Dew', 'Temptation' and green honeydew melons at commercial maturity in 2004 and stored up to 10 days in air at 5 °C. Data for each cultivar were fitted to spline lines. Within time periods, symbols labeled with the same letter are not significantly different using Sidak-adjusted means comparison ($\alpha \leq 0.05$).

is relatively well maintained during storage of fresh-cut chunks processed from all genotypes evaluated.

Kramer firmness of fresh-cut melon chunks varied depending on genotype, growing season and fruit maturity at the time of processing. In 2003, the firmness of freshly cut chunks of 'Temptation' was between 60 and 70% of that of freshly cut chunks from other melon genotypes. For freshly cut chunks from 2004-grown melon cultivars at commercial maturity, 'Orange Dew' was firmest, followed by 'Honey Gold' and green honeydew, 'Temptation' and the cantaloupe, with 'Orange Dew' being more than twice as firm as the cantaloupe (Fig. 5a). Firmness generally did not differ significantly among genotypes in 2004-grown melons at full slip,

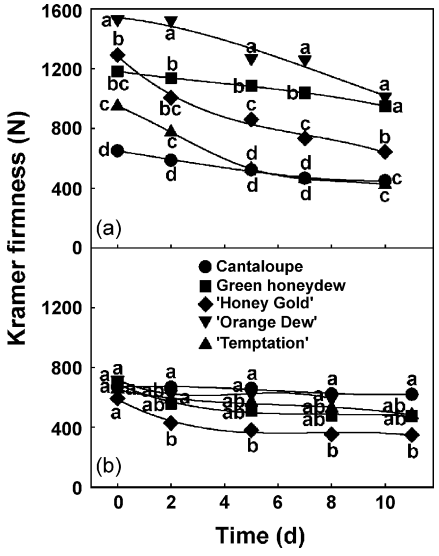

Fig. 5. Kramer firmness of fresh-cut chunks of cantaloupe, 'Honey Gold', 'Orange Dew', 'Temptation' and green honeydew at commercial (panel a) and full-slip maturity (panel b) in 2004 and stored for up to 11 days in air at 5 °C. Data for each cultivar were fitted to spline lines. Within time periods within panels, symbols labeled with the same letter are not significantly different using Sidak-adjusted means comparison ($\alpha \leq 0.05$).

although 'Honey Gold' was slightly, but significantly, less firm than the other cultivars (Fig. 5b). Freshly cut chunks from orange honeydew breeding lines had the same firmness as those of 'Orange Dew' and showed similar levels of softening with increasing fruit maturity (data not shown). Among orange honeydews, 'Temptation' was consistently less firm than the other genotypes at commercial maturity. Firmness variations among honeydew genotypes across seasons were small compared to the 60% decrease in cantaloupe firmness between 2003 and 2004 (data not shown).

During storage, the firmness of fresh-cut chunks from commercially mature fruit of all genotypes decreased between 20 and 50% with the orange honeydew cultivars softening at the same rate or faster than the green honeydew or the cantaloupe (Fig. 5a). A similar firmness loss, albeit at a reduced magnitude, occurred during storage in chunks processed from melons at full-slip maturity (Fig. 5b). In 2004, sensory evaluations were performed using chunks stored for 5 days, and all chunks appeared to be of salable quality. However, by day 8, some of the chunks processed from full-slip melons of all genotypes were showing signs of senescence as indicated by an uneven pattern of tissue translucency with the greatest deterioration occurring in cantaloupe and 'Orange Dew' (authors' observation).

3.3. Sensory evaluations

For sensory evaluations in 2003, we chose to compare fresh-cut chunks of cantaloupe and honeydew when all genotypes had the same SSC (Table 1). With SSC apparently not a major consideration, cantaloupe and orange honeydews were generally liked equally well in texture and flavor acceptability and overall eating quality by participants in the Public Field Day 2003 trial with 'Temptation' scoring highest (Table 3). The acceptability of the texture of 'Temptation' in 2003 was rather surprising because its Kramer firmness was only 60–70% of that of the other genotypes (data not shown). Also surprising was the finding that cantaloupe and the orange

Table 3
Sensory attributes scored for fresh-cut melon chunks from cantaloupe and honeydew genotypes by sensory evaluation panel volunteers in 2003

Genotype	Sensory attribute		
	Texture acceptability	Flavor acceptability	Overall eating quality
Cantaloupe	61.8b	63.3a	63.6ab
Green honeydew	62.9b	58.5b	61.4b
Temptation	72.2a	69.4a	70.2a
Line 4470	65.8ab	61.2ab	65.4ab
Line 4471	66.2ab	65.9ab	65.9ab
Line 4524	62.9ab	65.9ab	66.7ab

Attribute scores were from 480 consumers evaluating fresh-cut chunks from commercial maturity melons. Means of four 120-member replicates are presented: for each replicate, $N = 120$ for cantaloupe and green honeydew and $N = 24$ for each orange honeydew genotype. Means within the same columns followed by the same letter are not significantly different by Sidak-adjusted means comparison ($\alpha \leq 0.05$).

Table 4
Sensory attributes scored for fresh-cut melon chunks from cantaloupe and honeydew genotypes by sensory evaluation panel volunteers in 2004

Genotype	Sensory attribute						
	Appearance	Textural intensity	Textural acceptability	Sweetness	Flavor intensity	Flavor acceptability	Overall eating quality
Cantaloupe	70.9ab	59.4bc	60.0bc	44.3c	49.7b	48.0b	48.1b
Green honeydew	73.3a	58.3bc	63.0bc	64.0a	57.9ab	62.7a	62.3a
Orange Dew	76.8a	65.3ab	67.6ab	61.1ab	58.5ab	61.3ab	61.5ab
Temptation	58.3cd	49.5c	62.1bc	65.7a	63.5a	65.4a	64.3a
Honey Gold	54.7d	49.1c	55.0c	62.5ab	57.0ab	57.7ab	56.2ab
Line 4470	73.2a	68.3ab	72.7a	60.6ab	57.7ab	64.6a	63.5a
Line 4471	65.0bc	74.8a	68.4ab	51.0bc	49.7b	53.4ab	54.0ab
Line 4524	65.4b	73.5a	65.5ab	54.8abc	52.2ab	58.0ab	58.0ab

Attribute scores from 2004 sensory evaluations of fresh-cut chunks processed from commercially mature and full-slip melons. Means within the same columns followed by the same letter are not significantly different by Sidak-adjusted means comparison ($\alpha \leq 0.05$).

honeydews had the same flavor acceptability (Table 3) even though the cantaloupe had, with some notable exceptions, higher aromatic volatile concentrations than those of 'Temptation' (Table 2) and the other orange honeydews (data not shown). While generally not significant ($\alpha \leq 0.05$), the green honeydew scored lowest in flavor acceptability and overall eating quality and among the lowest in textural acceptability compared to the other genotypes (Table 3).

Consumer acceptance of melons is most often driven by sweetness (Bianco and Pratt, 1977), but also by an acceptable aroma (taste), i.e., by the presence of aromatic volatiles. However, SSC above 8% is not always directly associated with melon sweetness, flavor or overall acceptability (Aulenbach and Worthington, 1974). Furthermore, SSC and aromatic volatiles may both contribute to melon sweetness in terms of human perception since a number of specific aromatic volatiles in melons have a sweet aroma (Table 2).

In 2004, sensory evaluations were performed on fresh-cut chunks from commercial and full-slip maturity melons where SSC varied among genotypes and across maturity levels (Table 1). The 2004 evaluations were also performed under more rigid conditions than in 2003, which allowed intensity as well as acceptability characteristics to be evaluated and compared. 'Orange Dew' and 'Honey Gold' were also added to provide additional orange honeydew genotypes being grown commercially in the United States. Sweetness, flavor intensity and acceptability and overall eating quality—but not in appearance or textural properties—were scored higher in melon chunks from fruit at full-slip maturity compared to those from commercially mature melons. However, the differences in sensory attributes between the two maturity stages were always small (<8%) and were considered to have no practical meaning. While all sensory attributes scored in the acceptable (40–70%) range, there were meaningful differences among some of the genotypes for each sensory attribute (Table 4). Panelists liked the appearance of melon chunks from the green honeydew, cantaloupe and several uniformly orange honeydews better than the bi-colored appearance of 'Temptation' and 'Honey Gold' chunks (Table 4). Panelists associated the incomplete orange hue development of the flesh, i.e., bi-colored appearance, of 'Temptation' and 'Honey Gold' chunks in 2004 with incomplete removal of the green rind tissues from the orange flesh. Had the 2004 growing season been more suitable for melon growing, appearance scores probably would have been higher, at least for those genotypes having bi-colored flesh. Sensory firmness for orange honeydew breeding lines was scored firmer than 'Temptation' and 'Honey Gold' (Table 4) and was directly correlated to differences in Kramer firmness between the two groups of orange honeydews (data not shown). The firmness scores for cantaloupe, green honeydew and 'Orange Dew' were intermediate between the two groups of orange honeydews (Table 4). Textural acceptability scores followed the same trend as sensory firmness except that 'Temptation' scored fairly high despite its relatively low sensory firmness score (Table 4). Orange and green honeydew genotypes were generally sweeter than cantaloupe (Table 4), attributable to the generally higher SSC in honeydew genotypes vs. cantaloupe in 2004 (Table 1). The flavor intensity and acceptability of honeydew genotypes were also generally higher than those for cantaloupe, with 'Temptation' scoring highest. While cantaloupe had the highest aromatic volatile concentrations among the genotypes evaluated, the flavor of honeydews in 2004 was still preferred to that of cantaloupe. This was probably due, at least in part, to the higher SSC in honeydews versus cantaloupe in 2004. Overall eating quality of the orange and green honeydews was generally scored higher than that of cantaloupe in 2004 (Table 4) whereas in 2003, honeydews and cantaloupe were equally well liked (Table 3). The main differences among the genotypes between years were the lower SSC and Kramer firmness of cantaloupe and the higher SSC of honeydews in 2004 versus 2003 (Table 1, Fig. 5a). These sensory results are in general agreement with the earlier finding that consumer acceptance of melon products is driven most often by sweetness (Bianco and Pratt, 1977).

3.4. Microbial analyses

For melon chunks processed from commercially mature fruit, the initial populations of aerobic bacteria and fungi (yeasts and molds) were low and remained low during the first 5 days storage (Table 5). Thereafter, microbial populations

Table 5
Microbial counts of fresh-cut melon chunks prepared from commercially mature and full-slip cantaloupe and honeydew genotypes and stored up to 11 days in air at 5 °C

Genotype	Microbial counts (log CFU kg^{-1})							
	day 0		day 5		days 7–8		days 10–11	
	Bacteria	Fungi	Bacteria	Fungi	Bacteria	Fungi	Bacteria	Fungi
Commercial maturity								
Cantaloupe	<4.6	<4.6	4.7	<4.6	5.9a	5.6a	7.4a	7.3a
Green honeydew	<4.6	<4.6	<4.6	<4.6	<4.6	<4.6	4.8b	4.8b
Orange Dew	<4.6	<4.6	<4.6	<4.6	5.1b	<4.6	5.2b	4.8b
Temptation	<4.6	<4.6	<4.6	<4.6	<4.6	<4.6	4.8b	4.8b
Honey Gold	<4.6	<4.6	<4.6	<4.6	4.8bc	4.7b	4.8b	5.1b
Line 4470	<4.6	<4.6	<4.6	<4.6	4.6c	<4.6	5.1b	4.8b
Line 4471	<4.6	<4.6	<4.6	<4.6	4.9b	<4.6	5.2b	4.7b
Line 4524	<4.6	<4.6	<4.6	<4.6	<4.6	<4.6	4.8b	4.6b
Full slip								
Cantaloupe	<4.6	<4.6	5.8a	4.7a	7.2a	6.2a	8.8ab	8.1a
Green honeydew	<4.6	<4.6	4.6b	<4.6	6.2bc	5.5ab	8.3b	6.3c
Orange Dew	<4.6	<4.6	6.3a	5.0a	7.9a	6.0a	9.1a	7.0b
Temptation	<4.6	<4.6	4.8b	<4.6	6.5c	5.4b	7.6c	6.3c
Honey Gold	<4.6	<4.6	4.7b	<4.6	6.8ab	5.5b	8.4b	7.0bc
Line 4470	<4.6	<4.6	<4.6	<4.6	6.5bc	4.9c		
Line 4471	<4.6	<4.6	<4.6	<4.6	6.7b	5.4b		
Line 4524	<4.6	<4.6	<4.6	<4.6	6.8b	5.0c		

Fresh-cut chunks from commercially mature and full-slip melons were evaluated on days 7 and 8, respectively, and on days 10 and 11, respectively. Within maturity groups, means in the same columns followed by the same letter are not significantly different by Sidak-adjusted means comparison ($\alpha \leq 0.05$).

increased as storage time increased, with bacterial populations exceeding fungal populations as previously observed (Saftner et al., 2003). By day 7, microbial populations on cantaloupe chunks were higher than those on chunks from any of the honeydew genotypes.

For melon chunks from full-slip fruit, microbial populations were low during only the first 2 days storage, then increased rapidly during the remainder of storage. By day 5, bacterial and fungal populations were generally higher on cantaloupe and 'Orange Dew' chunks than on chunks of the other genotypes. Melon chunks from full-slip fruit of all genotypes had higher microbial counts than corresponding chunks processed from commercial maturity fruit. The high microbial load on chunks processed from full-slip 'Orange Dew' was associated with the development of some netting on the rind of many fruit as they ripened. Netting on melon surfaces is known to harbor microbes which can contaminate the flesh during fresh-cut processing (Suslow and Cantwell, 2001). The high microbial loads on chunks of cantaloupe and full-slip 'Orange Dew' after 7 days storage were correlated with minor pitting on the surfaces of those chunks and with increasing respiration rates on corresponding chunks after day 8 storage (data not shown).

4. Conclusions

Consumers liked the flavor, texture, sweetness, and overall eating quality of the orange honeydews as well as or better than those of cantaloupe and green honeydew. Microbial quality was better maintained in honeydew chunks than in cantaloupe chunks during storage, at least when commercially mature fruit were used for fresh-cut processing. 'Temptation' generally scored highest among the orange honeydews for flavor intensity and acceptability, overall eating quality and aromatic volatile concentrations including the nonenyl and nonadienyl acetates, which are believed to contribute to honeydew aroma and flavor. 'Orange Dew' scored highest for appearance, orange hue and β-carotene concentration and lowest for microbial quality—at least at full-slip maturity—among orange honeydews. However, all fresh-cut chunks of orange honeydews maintained their quality during storage in air at 5 °C for at least 8 days. Orange honeydews were distinctive from cantaloupe and green honeydew in having relatively high concentrations of nonenyl and nonadienyl acetates, which may contribute to their unique aroma and flavor among melons. Overall results indicate that orange honeydews are a promising new melon type for fresh-cut processing.

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